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PHYSICAL RESEARCH PROGRAM

REPORT

OF THE

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT

TO THE

JOINT COMMITTEE ON ATOMIC ENERGY
CONGRESS OF THE UNITED STATES

AUGUST 1958

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LETTER OF TRANSMITTAL

CONGRESS OF THE UNITED STATES,
SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C., August 22, 1958.

Hon. CARL T. DURHAM,
Chairman, Joint Committee on Atomic Energy.

DEAR MR. CHAIRMAN: Transmitted herewith is a report by the Subcommittee on Research and Development based on public hearings held by the subcommittee last February on the Commission's physical research program. During the course of the hearings some 50 of the Nation's leading research scientists from our laboratories and universities appeared before the subcommittee to describe the activities of the working scientists in the field.

It is hoped that the printed hearings, together with this report, will assist in providing a better understanding on the part of the Congress and the public of what basic research actually is and the important role which such research plays in our overall program of scientific advancement in this country.

Sincerely yours,

MELVIN PRICE,
Chairman, Subcommittee on Research and Development.

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REPORT ON THE PHYSICAL RESEARCH PROGRAM

INTRODUCTION

Few people question the need for the United States and the rest of the free world to pursue a vigorous and effective program of basic research. Exploration of the scientific frontier is not only a desirable objective for its own sake but has become a vital necessity to this Nation in its efforts to maintain America's leadership in scientific advancement. This need has been underlined dramatically by recent developments in the field of science, both here and abroad.

In November of 1956, Khrushchev made his famous boast to western diplomats: "Whether you like it or not history is on our side. We will bury you." More than once in the past the free world has made the grievous error of underestimating the importance of such boasts. With what we know now of Soviet plans to overtake the free world in scientific advancement, it is imperative that we pursue an effective program of scientific development designed to insure that United States and the rest of the free world will, in the coming years, meet this threat effectively.

But beyond the Soviet threat, there is an equally pressing need for the United States to move ahead vigorously in rolling back the frontiers of science for the betterment of all, both here in this country and throughout the world. This is indeed a worthy objective and one which should command our full energy and devotion.

History has demonstrated that discoveries made in the course of basic research work underlie all progress in the so-called practical applications of science. Most of the present-day wonders of our scientific age could not have been realized without discoveries which were made by research scientists in years gone by. Doubtlessly, these scientists had little or no idea what practical applications would spring forth directly from those discoveries at the time they were made.

It is equally true that the position of nations in the modern day world is directly tied to their degree of effort in scientific research and that those nations which neglect such research will be relegated in future years to second-class status.

Together with the development of a vigorous program of basic research in this country, we must recognize the close interdependence of the free-world scientific community and the importance of removing barriers to the full exchange of information and scientists among the nations of the free world. The United States can be justifiably proud of the high quality and competence of our own scientists in this country and of the remarkable work they are performing in our laboratories and institutions of higher learning. At the same time our own scientists would be the first to admit that we have no monop-

oly on brains in the field of scientific advancement and that we must bend every effort to see that maximum opportunities are provided for the free interplay of ideas among scientists throughout the free world.

In order to accomplish these objectives it is essential that the Congress, the executive branch and the public at large have a thorough understanding of our national needs in the field of basic research and that they lend their wholehearted support to a vigorous and effective research effort in the years to come. An essential ingredient of any such program is the willingness and determination on the part of all of us to back up our intentions with adequate financial support of this undertaking. Our hardworking scientists urgently need and deserve such support. To do less would be to risk America's world leadership in scientific advancement, with all this implies for our future security and well-being.

I. BACKGROUND OF HEARINGS

Impressed with the need for a better understanding on the part of the Congress and the public of our national needs in the field of physical research, as it relates to the field of atomic energy, the Subcommittee on Research and Development scheduled an extensive series of public hearings last February to receive the "working level" views of some 50 leading scientists from our laboratories and universities throughout the country. The hearings were held on February 3, 4, 5, 6, 7, 10, 11, 13 and 14, 1958, and are recorded in nearly 800 pages of testimony covering the major research areas of chemistry, metallurgy, physics, and controlled thermonuclear reactions.

Aside from the aim of compiling this material for the use of Congress, the scientific community and the lay public, the subcommittee also sought to provide an opportunity for the working scientists in the field—the people who do the actual research work in our laboratories and universities—to come before the Congress to express through selected examples of their work, what basic research really is and means to the future of our country. The subcommittee hoped that through such direct contact with the working scientists, the Congress and public would gain a better appreciation of the progress and problems being encountered in the AEC physical research program and, at the same time, the hearings would serve to demonstrate congressional interest and support of our scientists in the field. The hearings were patterned on similar public hearings held by the subcommittee in 1955 and 1956 on atomic research in the fields of biology, medicine, agriculture, and food preservation.

The schedule of the hearings, including the material covered and the names of the scientists making the presentations, is as follows:

Monday, February 3, 1958

A general survey discussion by three leading scientists in the physical research program:

I. Chemistry survey: Dr. Glenn T. Seaborg, University of California.
II. Materials survey: Dr. Frederick Seitz, University of Illinois.
III. Physics survey: Dr. Isidor I. Rabi, Columbia University.

Tuesday, February 4, 1958

A discussion by the working scientists of selected research topics in the field of chemistry:

I. Introduction: Dr. Paul W. McDaniel, Acting Director, Division of Research, Atomic Energy Commission.
II. Nuclear chemistry:
A. Chemical studies of high-energy nuclear reactions: Dr. Gilbert Friedlander, Brookhaven National Laboratory.
B. Nuclear properties of the heavy elements: Dr. John O. Rasmussen, University of California.
C. Studies of the fission process: Dr. John R. Huizenga, Argonne National Laboratory.

III. Radiation chemistry:

A. Effects of high-energy radiation on organic compounds: Dr. Milton Burton, University of Notre Dame.

B. Radiation chemistry of water: Dr. A. O. Allen, Brookhaven National Laboratory.

C. Behavior of water in reactors: Dr. Edwin J. Hart, Argonne National Laboratory.

IV. Hot atom chemistry: Dr. John E. Willard, University of Wisconsin.

Wednesday, February 5, 1958

Continuation of chemistry research discussion and questions:

I. High temperature chemistry: Dr. Paul W. Gelles, University of Kansas.

II. The use of isotopes in the quantitative description of the rate of chemical reactions: Dr. Jacob B. Biegeleisen, Brookhaven National Laboratory.

III. Selected topics in physical and inorganic chemistry:

A. Paramagnetic resonance studies of free radicals produced by radiation: Dr. Ralph Livingston, Oak Ridge National Laboratory.

B. Studies of molecular structure by neutron diffraction: Dr. Henri A. Levy, Oak Ridge National Laboratory.

C. Liquid-liquid extraction techniques for the separation of lanthanide and actinide elements: Dr. Donald F. Peppard, Argonne National Laboratory.

D. Ion exchange as a research tool in the separation of rare earths: Dr. Jack E. Powell, Iowa State College.

E. Geochemical studies: Dr. Harold C. Urey, University of Chicago.

Thursday, February 6, 1958

A discussion by the working scientists of selected research topics in the fields of metallurgy, solid state physics, ceramics, and radiation effects on solids:

I. Effects of imperfections and their interactions on the properties of crystalline solids: Dr. David K. Holmes, Oak Ridge National Laboratory.

II. Atomic motion in solids-diffusion: Dr. David Lazarus, University of Illinois.

III. Theory of alloys: Dr. Benjamin L. Averbach, Massachusetts Institute of Technology.

IV. The microstructure of metals and some effects of explosive shock thereon: Dr. Cyril S. Smith, University of Chicago.

V. Fundamental corrosion studies: Dr. Joseph E. Draley, Argonne National Laboratory.

VI. Radiation effects in materials: Dr. G. J. Dienes, Brookhaven National Laboratory.

Friday, February 7, 1958

A discussion by the working scientists of selected research topics in the field of physics:

I. Low Energy and Medium Energy Nuclear Physics:

A. Basic concepts: Dr. John H. Williams, University of Minnesota.[1]

B. Low-energy neutron physics: Dr. William W. Havens, Jr., Columbia University.

C. Nuclear spectroscopy: Dr. William W. Buechner, Massachusetts Institute of Technology.

D. Gamma radiations from excited states of light nuclei: Dr. Tom W. Bonner, Rice Institute.

E. The nonconservation of parity: Dr. Tsung-Dao Lee, Columbia University.

Monday, February 10, 1958

A discussion by working scientists of selected aspects of the controlled thermonuclear research program:

I. Introduction: Dr. Arthur E. Ruark, Division of Research, United States Atomic Energy Commission.

II. Problems in obtaining controlled thermonuclear temperatures: Dr. Richard F. Post, University of California.

[1] Dr. Williams was subsequently appointed Director, Division of Research, Atomic Energy Commission.

III. Magnetic bottles for plasmas:
Dr. Melvin B. Gottlieb, Princeton University.
Dr. Edward A. Frieman, Princeton University.
IV. Pinch discharges:
A. Neutrons from pinches: Dr. James L. Tuck, Los Alamos Scientific Laboratory.
B. The "false neutrons": Dr. Stirling A. Colgate, University of California Radiation Laboratory.
C. The stabilized pinch: Dr. James A. Phillips, Los Alamos Scientific Laboratory.
D. The turbulent pinch: Dr. Keith Boyer, Los Alamos Scientific Laboratory.

Tuesday, February 11, 1958

Continuation of physics research discussion and questions:
I. High energy physics:
A. Multi-Bev. accelerator experiments:
Part I—Examples of high energy physics research at the bevatron: Dr. Luis W. Alvarez, University of California. Part II—Properties of K-mesons and hyperons: Dr. R. K. Adair, Brookhaven National Laboratory.
B. Interactions of electrons with nucleons and nuclei: Dr. Robert Hofstader, Stanford University.
C. Elementary particles: Dr. Murray Gell-Mann, California Institute of Technology.
D. Cosmic ray research: Dr. Bruno B. Rossi, Massachussets Institute of Technology.
E. Cosmic ray research with rockets and satellites: Dr. James A. Van Allen, University of Iowa.

Thursday, February 13, 1958.

Continuation of physics research discussion and questions:
I. Computers:
A. University research computers: Dr. Nicholas Metropolis, University of Chicago.
B. Monte Carlo studies of nuclear chain reactions: Dr. Robert Richtmyer, New York University.
II. High energy accelerators:
A. The Brookhaven alternating gradient synchrotron: Dr. George K. Green, Brookhaven National Laboratory.
B. 15–45-Bev. electron linear accelerator: Dr. Leonard I. Schiff, Stanford University.
C. Fixed field alternating gradient systems: Dr. Keith R. Symon, University of Wisconsin.

Friday, February 14, 1958.

Review of the physical research program and the level of support needed.
Dr. Alan T. Waterman, Director, National Science Foundation.
Dr. P. W. McDaniel, Acting Director, Division of Research, Atomic Energy Commission.

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II. HIGHLIGHTS OF PRESENTATIONS

During the course of the hearings the subcommittee received detailed testimony concerning the work which is being undertaken in our laboratories and universities in the major areas of physical research. Much interesting information was developed concerning individual research projects and their relationship to so-called practical applications of science. In its entirety, the testimony is eloquent proof of the vital role which basic research occupies in the advancement of American science. It also demonstrates graphically the interdependence of research work being performed in the three major disciplines of physical research: chemistry, metallurgy, and physics. Highlights of the presentations made by scientists working in these three basic areas, together with those working in the field of controlled thermonuclear reactions, follows:

A. CHEMISTRY

The first several days of the hearings were devoted to research work being undertaken at AEC laboratories and universities in the field of chemistry. This work includes research in transuranium elements, solvent extraction, ion exchange, high temperature chemistry, corrosion research, radiation chemistry, and radioactive and stable isotope tracer research.

Among the many interesting experiments being conducted by our research scientists are chemical studies of residual nuclei remaining after nuclear reactions. Studies using the Brookhaven high energy accelerator—or cosmotron as it is called—have shown that even with bombarding energies in the billion-electron-volt range, some very simple nuclear reactions take place that may serve as a probe into some detailed features of nuclear structure.

The creation of synthetic elements by intense nuclear bombardment has led to a new theory on the creation of supernovae—the large stars that flame to brilliance and explode. According to this new theory supernovae are, in fact, giant atomic furnaces with an intense flux of neutrons. The neutrons within the exploding star transmute or change its elements such as the radioactive form of californium, one of the synthetic elements created in minute quantities in our laboratories.

In the field of radiation chemistry, studies are being conducted into the effects of high energy radiation on organic materials. When high energy radiation travels through matter it produces ions, electrons, excited molecules, light and heat. In the vapor state, positive ions react very rapidly with ordinary molecules in ways which have heretofore been unsuspected. Such reactions may become very important for organic synthesis and may have had considerable significance in the evolution of our atmosphere. These studies also have a direct bearing on the development of possible materials for reactor coolants.

Research is being conducted on the radiation chemistry of water, and its various ramifications. The effects of radiation on water are important because of the use of water as a cooling medium and a neutron moderator inside nuclear reactors. These effects are also significant because of their possible influence on living organisms, which are 85 percent water.

Research in the field of high temperature chemistry has an important impact on our present pattern of living. Every kilowatt of power, except those from waterpower, has behind it a man-controlled high temperature operation. The chemist is interested in high temperatures not only because of their utilization but also because of the unusual chemical substances which are formed. For the testing of hypotheses and theories concerning chemical binding, high temperatures are useful because they frequently cause simpler reactions, faster reactions, and more favorable conditions for a desired product.

Radioactive isotopes, which have often been called the wonder tool of the atomic age, are being utilized in research on the rates of chemical reactions. The separation of isotopes depends upon differences in their physical and chemical properties. These differences can be utilized to obtain basic information about molecular structure, sometimes inaccessible by other methods.

An example of the practical utility of knowing chemistry reaction rates is provided by the case of the huge gaseous diffusion plant at Oak Ridge, which produces uranium 235. The rate of diffusion of uranium 235 and uranium 238 through porous screening devices differs by about one-half of 1 percent. If we are forced to consider a process with a diffusion rate difference of one-twentieth of 1 percent, only a small difference, it would require the construction of a diffusion plant 100 times larger than the present one at Oak Ridge and at a considerably higher cost, running into billions of dollars.

Interesting studies are being undertaken concerning the accurate location of lightweight atoms present in the molecule with heavy atoms, particularly with the study of crystals containing the lightest of all atoms, hydrogen. Hydrogen, as a constituent of many substances of scientific and technological importance, including all biological material, has long been recognized as playing an important role in chemical binding.

Separation of the rare earths, or lanthanides as they are known, poses one of the more difficult problems in chemistry research because of the similar chemical properties which these elements possess. However, research in this field is important to the atomic-energy effort because of the similarity in chemical behavior of these rare earths to uranium and synthetically produced transuranium elements. A system for separating individual rare earths from each other is being developed, and other systems are being devised for the separation of transuranium elements from rare earth fission products. These studies are most helpful to our scientists in achieving a better understanding of chemical phenomena.

Research is also being undertaken in the separation of rare earths by ion exchange techniques. Development of synthetic exchangers in the past 2 decades has given the chemist and the chemical engineer a set of very useful tools for isolating heretofore difficult separable substances as well as revolutionizing the water-softening industry. In the past 10 years, there has been more progress in the fields of rare

earths separations and preparation of pure rare earth metals than in the entire period between the time that the first rare earth, cerium, was discovered in 1803 and the ion exchange separation of rare earths was announced in 1947.

Natural nonradioactive rare earths are of particular interest due to the variety of their nuclear properties. Some of them, when purified, have little affinity for neutrons and can therefore be used structurally in the form of alloys and ceramics in atomic reactors. Others have such an affinity for neutrons that they can be used in light-weight control devices for atomic reactors and as neutron shields. The variety of radiations from radioactive rare earths offers a great number of possibilities, such as the use of certain rare earths in medicine for the treatment of cancer and as portable X-ray sources. Some of the radiations are suitable for use in thickness gages and other such devices.

One of the most interesting applications of radioactivity by the research chemist is in the determination of the age of rocks, meteorites, and other matter as a means of calculating the age of the solar system. Since the war several methods have been developed for determining the ages of rocks very reliably. The methods have been well understood for a half century but the precision and reliability were very poor, especially when the concentrations of the radioactive elements were very low.

Calculations based on the rates of radioactive decay of uranium to lead indicate that the age of the solar system is about 4.5 to 4.6 billion years. Similar studies of the decay of rubidium to strontium indicate the nearly identical time of 4.7 billion years. Results of other computations indicate the somewhat smaller range of 4 to 4.5 billion years. Taken together, these studies lead to the conclusion that a very complex process took place about 4½ billion years ago and that this can reasonably be considered as the minimum age of the solar system.

Other studies, together with these dates have led to a better understanding of some processes which took place in the distant past. The physical structures of the meteorites indicate that objects as large as our moon were formed early in the history of the solar system, that they were broken into very small fragments, and then reaccumulated into the planets.

Aside from their value in determining the age of the solar system, these studies have given us a better understanding of the abundance of the elements. This is of great importance to the nuclear physicists working on the problem of the origin of the elements. While this research work was not initiated with any idea of its practical importance, the results of this research may have a profound effect on many fields of activity, similar to the early research work done on the separation of isotopes.

B. METALLURGY AND MATERIALS

Following the presentations on chemical research, the subcommittee received detailed testimony on work which is being performed in the area of metallurgy and materials research. It was emphasized that although the field of atomic energy had received its greatest impetus from developments in physics, it has, from the beginning, been de-

pendent in a critical way upon the materials available. Prior to 1950, metallurgical and materials research was purely a trial and error technology. Since that time it has become a science. The field of atomic energy has had a great deal to do with causing this change by providing some of the most useful tools for materials studies, such as reactors and high energy particle accelerators.

The importance of materials research in atomic-energy development becomes evident when it is realized that five separate categories of materials are found in a typical reactor. These are the fissionable material used for reactor fuel, the cladding of these fuels, the moderator and the reflector, the structural materials and shielding, and finally the coolants utilized in connection with reactor operations. Since these materials are used in environments of high temperatures and intense radiation, it is necessary to find out how they will stand up under these conditions.

During discussions on metallurgy and materials research it was pointed out that much of the attention of investigators in the field of solid state physics is directed toward the study of imperfections in the area of atoms in a crystalline solid and the influence of the presence of such imperfections on the external properties of materials. Such imperfections may strongly affect or even completely determine particular characteristics of a solid. The introduction of such defects, for example by various types of radiation, permits an evaluation of their direct and indirect effects on the properties of certain materials. The expected rewards from such research consist not only of an increased understanding of the behavior of all materials, which in most cases is determined by a very complicated series of interacting imperfections, but also an improved theoretical comprehension of solids.

Interesting research is also being conducted into atomic motion in solids. Such motion in fluids has long been familiar to the scientific community, but the observed rigidity of solids, reinforced by evidence indicating perfection of the basic structure of materials, long seemed to preclude the possibility of mass flow in the solid state. Contrary evidence has been provided by many interesting and important phenomena observed in research studies during the past two decades which could only be understood on the assumption of appreciable atomic motion.

The availability of radioisotopes of high activity and high purity, for use as tracers, has provided an opportunity for detailed study of such diffusion in solids. Using relatively simple techniques, it is possible to measure the diffusion of tracers with high precision and it has been observed, for example, that the diffusion motion within a solid is enormous at temperatures well below the melting point. While much work remains to be done before the basic phenomenon of diffusion in solids is thoroughly understood, it has been possible in recent years, by studying the variation of diffusion rates with temperatures and by determining the relative rates of diffusion of various impurities, to begin the development of an understandable theory on the movement of atomic matter within solids.

The importance of research on alloys was also emphasized during the course of the presentations. Pure metals are usually relatively soft and of limited usefulness. However, in adding alloy elements to a base material such as iron, it is possible greatly to increase the

strength and hardness of the resultant material and almost all of the practical metals and alloys in use today consist of carefully controlled solid solutions.

Our scientists are currently attempting to achieve a better understanding of how alloys are constructed on an atomic scale. Sensitive X-ray diffraction techniques have shown that in some alloys the atoms are not arranged at random but exhibit certain preferences for each other, while in other alloys the atoms tend to cluster together. The nature of the arrangements of the atoms affects the mechanical properties of the solution as well as the response to heat treatment.

It has also been shown, utilizing these new techniques, that atoms do not have a fixed size and that the atom of one metal in solution may be considerably smaller than another. This information indicates that atoms are not as rigid as previously believed and that they can squeeze or expand to accommodate themselves.

Recent measurements have shown that atoms in a solid solution are not located in a precise pattern as in a pure metal but are displaced, causing local distortions. It now appears that these local distortions may be of great importance in understanding how alloy additions can make a metal much stronger and more resistant to deformation.

It was pointed out that although this research program is of a fundamental nature and is directed toward basic problems, it is often possible to apply the results of such studies directly to a practical problem in the atomic-energy program. For example, data resulting from these studies on atomic arrangements are becoming of great interest in understanding the behavior of certain alloys in a reactor.

One area of materials research which has particular interest for our scientists and engineers working on reactor development is the field of corrosion studies. Most designers of water-cooled reactors find themselves unable to use preferred materials for construction or unable to operate at preferred conditions because of limitations imposed by corrosion. Efforts to avoid this problem by trial and error corrosion testing have met with only limited success. A fundamental research program on the nature of water corrosion may be necessary in order to make it possible to solve many of the current nagging problems.

Studies are currently being conducted on corrosion of aluminum over a wide temperature range with a view to determining its suitability for use in high-temperature water-cooled power reactors. At high temperatures commercially available aluminum alloys show rapid deterioration in water. As a result of these studies, means of preventing this rapid deterioration have been developed, including the introduction of suitable additives to the water or by the use of new alloys specifically designed for the purpose.

A byproduct of this investigation and of work dealing with the corrosion behavior of a number of metals in water has been the development of a theory concerning damage to metals by the hydrogen produced during the corrosion. At the preliminary stage of evaluation, the theory appears to offer real promise in explaining many corrosion phenomena and predicting means of affording better corrosion resistance. Similar studies are being conducted on corrosion resistant properties of zirconium, which is a valuable material utilized in the construction of power reactors.

The subcommittee also was informed of research studies currently being undertaken with regard to radiation effects on materials and

the central role which simple defects introduced by such radiation occupy in the practical applications of atomic energy. Our scientists are being assisted in their studies by devices in our laboratories which artificially create the concentration of defects in these materials by particle irradiation. Such irradiation induced defects are also being utilized in the study of the chemical reactivity of solids.

C. PHYSICS

A third major area of the physical research program is the field of nuclear physics and the subcommittee received detailed testimony regarding research work presently being conducted in this field. The major goal of research in nuclear physics is to understand the origin and nature of the enormously powerful forces which bind together the components (protons and neutrons) of the nucleus. Observations on the collisions of protons with protons and neutrons with protons provide experimental evidence on which to base a detailed theory on the nature of nuclear forces.

Our understanding of the behavior of the nucleus in terms of adding up all the interactions of its component parts is not complete in the sense that we cannot, as yet, understand and predict in detail why nuclei, for example, disintegrate, suffer fission or undergo fusion. Experiments on more complicated interactions than those experienced by two protons or a proton and a neutron constitute another approach designed to lead to a more complete understanding of the behavior of nuclei and ultimately a sufficiently detailed theory of the nucleus to allow prediction of as yet undiscovered phenomena.

Research in the field of nuclear physics might be said to comprise studies in three general areas: low energy, medium energy, and high energy physics. The low energy range might be roughly defined as that area where neutrons have energies below 10,000 electron volts.

Although the neutron was discovered 26 years ago and has been studied intensively, its structure is still a mystery. While we do not completely understand the neutron, we do know that it is a fundamental constituent of all nuclei and we have studied extensively its interactions with nuclei.

Many of the investigations with low energy neutrons have been performed with neutron "time-of-flight" spectrometers. Precise and costly devices such as these are used to determine how the area of the nuclear of many substances, or neutron "cross section" as the scientists call it, varies with energy. Large peaks in the neutron cross-section curves, called resonances, are observed and reveal information about the structure of the nucleus.

Research in this field of physics has practical importance because most of the neutrons in a reactor are in this energy region. Because we do not have experimental evidence over a wide range of energies for many elements, we have had to rely on large scale and expensive experiments, such as the building of test reactors, to determine what the properties of reactors will be.

One of the most interesting studies which the subcommittee was told about is the research work which has led to development of the "nonconservation of parity" concept. Detailed physical laws and the concept of symmetry have long been valuable in understanding the nature of atomic interactions, or forces. However, recent dis-

coveries with regard to the strange behavior of certain particles called K-mesons produced by high energy accelerators such as those at Berkeley and Brookhaven have led to the belief that the physical laws are not absolutely symmetrical, as previously thought, when applied to so-called "weak interactions." Since the initial discovery, nearly 100 experiments have been performed and have confirmed the new theory. This overturning of the traditional scientific concept of symmetry is having profound effects on scientific thinking in a number of related fields and is an excellent example of the importance to scientific progress of the close interplay between experiments and theory.

Some of the Nation's most important and significant research work in the field of high energy physics has centered around the 6.2 Bev. (billion electron volts) accelerator, better known as the bevatron, at the University of California Radiation Laboratory in Berkeley. Most of the experimental work with the bevatron has dealt with the production, interaction, and decay properties of the so-called strange particles, which were unknown when the bevatron was designed. Early studies of one variety of strange particles led to the discovery, mentioned above, that our previous ideas about parity were incorrect.

In addition to these phenomena, an interesting new reaction was found quite accidentally in the course of research with the bevatron. Particles called mu-mesons showed themselves capable of catalyzing the fusion action between hydrogen and deuterium at temperatures near absolute zero, whereas it had been generally believed that exceedingly high temperatures would be required to make light nuclei fuse. Although this discovery turned out not to be of practical importance, it is a useful reminder that an experiment in one area of physics can quite easily bear upon another area of research.

One of the most interesting presentations before the subcommittee was on research studies on elementary particles. The properties of the elementary particles provide the laws that underlie virtually all phenomena in science, since the particles are the building blocks of all matter. Many complications have arisen in this field over the last 30 years, but now some strikingly simple facts are emerging. Present research seems to be uncovering a universal law of "weak interaction," one of the four kinds of physical forces, and to be giving us clues as to the laws of so-called strong interactions, such as nuclear forces.

The questions of the laws of interaction and the structure of elementary particle families are expected to lead us into the realm of the very small distances where even our most successful theories break down. These regions are just being investigated by experiments at the present time, and no one knows what to expect. Many physicists believe that space and time may lose their usual meaning when such short intervals are involved.

Another interesting area of research is the study of cosmic rays, nuclei which rain down upon the earth from outer space. About 90 percent of these cosmic rays are nuclei of hydrogen (protons) with nuclei of helium (particles) as the second most abundant component. They differ from other rays, both of terrestrial and celestial origin, because of the much greater amount of energy concentrated in each individual particle. Cosmic ray studies are likely to have considerable repercussions on the science of astrophysics in the years ahead. In particular, the problem of the origin of cosmic rays appears to be

intimately connected with the problem of the dimensions and structure of our galaxy.

An attempt is being made to find out how large the energies of individual cosmic-ray particles can actually be and from which directions of the sky particles of the highest energy arrive. These high-energy particles are detected by observing the showers of secondary rays which they produce in the atmosphere. The largest shower observed had over a billion particles, indicating an enormous primary energy in electron volts of about 10 to the 19th power. This energy is greater than the maximum energy which, according to previous views, could be generated by an acceleration mechanism operating within our own galaxy.

Rockets and satellites are useful in cosmic ray research because they can transport cosmic-ray equipment to high altitude sites which are effectively above the earth's atmosphere. Hence, they make possible measurements on the primary radiation before its interaction with, and substantial modification by, the thick blanket of air which surrounds the earth. The nature of the energy spectrum of the primary cosmic radiation has been remarkably clarified by this work and a new type of radiation has been discovered to be associated with auroras in both northern and southern polar regions. The most recent measurements suggest a connection between the occurrence of auroras and fluctuations of the cosmic-ray intensity and the earth's magnetic field. It is possible that the phenomena associated with passage of solar gas through the earth's magnetic field may be closely related to the mechanism by which cosmic rays are occasionally produced in significant members on the sun.

A simple cosmic-ray apparatus, developed at the State University of Iowa, under a research contract with AEC, was flown in our first satellite, Explorer I, and a large volume of information on cosmic-ray intensity has been obtained from this device. This information is comprehensive in coverage to an extent impossible to achieve by other means and will make possible detailed plotting of the effective magnetic field of the earth as it exists in outer space.

It was pointed out during the physics discussions that an important research tool employed in the field of nuclear physics is found in the complex computing devices which have been developed to assist our research scientists. As these computers become more common in our laboratories, much of the detailed calculation work in the mathematics and other fields, which previously had to be done by individual scientists with pencil and paper, can be performed in a fraction of the time previously required, thus freeing the scientists for actual experimental work.

The development of computers has far outdistanced the mathematical development of computing methods for using these machines and it was emphasized that greater use should be made of these devices, particularly in our universities. There is little doubt that these machines have enabled the fields of basic research and applied research to progress faster than would otherwise have been possible if we had had to continue to rely on conventional calculation techniques.

The vital importance to the whole physical research program of large scale particle accelerators or "atom smashers" was graphically described to the subcommittee by some of the leading accelerator

designers in this country. It was repeatedly pointed out that such large-scale accelerators, which are expensive to build and operate, are essential to the work of our scientists in their efforts to unravel the mysteries of the atomic nucleus.

The transmutation or change of an element was first accomplished by a particle accelerator in 1932. Since then research requirements attending the rapid development of nuclear physics have led to the construction of larger and more refined accelerators. As the energies available in the laboratory began to reach the largest amounts needed for study of nuclear structure, the discovery of the so-called strange short-lived particles produced a demand for still higher accelerator energies. The Brookhaven National Laboratory proton synchrotron, or "cosmotron," one of our first really large accelerators in this country, exceeded a billion electron volts (Bev.) in 1952 and subsequently reached 3 Bev., before a major breakdown required the cessation of operation for repairs.

Even while the cosmotron was being brought into stable operation condition, and the University of California bevatron was being constructed to produce energies of 6 Bev., studies began on the problem of designing a feasible machine of yet higher energy. These studies were prompted by the realization that research into the particles which comprise the atomic nucleus is going to require energies of 25 to 100 Bev. in the immediate future.

It became apparent that any process of scaling up the constant-gradient, or "weak focusing," proton synchrotron type much beyond 10 Bev. would lead to enormous and costly magnet systems. Invention of the alternating-gradient focusing principle made possible the design of proton synchrotrons of great diameter, but with magnets of relatively small size.

The largest and most powerful particle accelerator presently under construction in this country is the alternating-gradient synchrotron at the Brookhaven National Laboratory, which is designed to reach energies of 25 to 30 Bev., and will cost about $29 million. The diameter of the machine is over 800 feet and the chamber through which particles will be accelerated, almost at the speed of light, is about one-half mile in circumference. The device, employing the so-called strong focus principle, requires great precision in fabrication and has involved intensive development work. In fact, design will be proceeding even after the machine is "completed" in 1960. Machines so long in construction are virtually obsolescent by the time they are assembled and are improved or reconstructed almost continually to keep up with the demands of research.

Another major research tool which is under study is a 15–45 Bev. linear accelerator proposed by the Stanford Research Institute, which is to be built in an underground tunnel 2 miles long. One objective of the device is to make a systematic research of new particles of a certain class not now accessible to study with conventional proton accelerators. Since only two particles in this class are known at present (the electron and the mu-meson) the range in which this program will become effective cannot be foreseen but may involve whole new important fields of scientific inquiry. Estimated cost of the device is about $78 million.

A second large accelerator which has been proposed, in this instance by the Midwestern Universities Research Association or MURA

group, is designed to produce energies equivalent to 540 Bev. through utilization of colliding beams of protons within a single accelerator assembly. This proposed device is aimed primarily at increased beam intensity and extending the energy available well into the multi-Bev. region. Estimated cost of the machine and its supporting facilities has been placed at $100 million.

D. CONTROLLED THERMONUCLEAR RESEARCH

A fourth major area of the physical research program is experimentation with controlled thermonuclear reactions through which it is hoped we may some day learn to utilize for peaceful purposes the vast energy released in the fusing of heavy hydrogen atoms. Research in this area involves technical problems of great complexity covering a wide range of scientific investigation. But the promise of gaining virtually limitless quantities of power through the fusing of elements readily available in the oceans has captured the world's imagination and has served to spur research efforts in this field, both in the United States and abroad.

The scientists in our laboratories who are conducting research into controlled thermonuclear reactions have essentially three successive goals: (1) to obtain temperatures so high that the nuclear power produced by the hot gas in the reactor exceeds the intense radiation which tends to cool the gas; (2) to develop a device which puts out more power than is put into it; and (3) to develop an economic power producing reactor.

The first goal has not yet been reached and so far there is no definite proof it can be reached. Even though recent progress in both the United States and Britain has greatly increased the hopes of our scientists, the work in this area is considered to be a long-term research effort.

As far as is known at the present time, the only avenue to fusion power is through the confinement of a very hot ionized gas (plasma) by means of intense magnetic fields. The hot gas must be confined long enough to allow many nuclear reactions to occur and thus release energy in the form of heat. There are always leaks of particles out through the magnetic lines due to pressures built up by the high temperatures necessary for producing thermonuclear reactions. But these losses can be lived with provided the ionized gas or plasma can be kept pure enough.

At the high temperatures required for controlled thermonuclear reactions, it is essential to keep the hot plasma off the container walls. One ingenious method developed by our scientists to do the job is through the employment of a "magnetic bottle." This consists of a magnetic field created by passing large electric currents through the plasma or by means of currents in external coils.

This "magnetic bottle" is, at best, a leaky one and the minimizing of these leaks is a prime objective. Another major objective is achieving sufficient stability of the hot gas or plasma confined by the magnetic fields during the time nuclear reactions are taking place. Without such stability, the plasma has a tendency to throw itself against the walls and the forces in the system are thrown out of balance.

Since 1954 our scientists have been observing neutrons being produced in several kinds of devices. The cumulative evidence obtained during 1954–55 in the course of studies of these neutrons strongly indicate a true thermonuclear reaction. However, physical phenomena associated with the production of these neutrons did not support this evidence and subsequent experiments proved decisively that the neutrons were in fact of nonthermonuclear origin. These are the so-called "false" neutrons which were encountered first by our scientists and later by British scientists in experiments with their "zeta" machine.

The temperature of the plasma in most neutron-producing experiments conducted to date has been found to be below the thermonuclear range. In some cases this has conclusively proved the absence of a thermonuclear plasma. It was pointed out, in this connection, that regardless of what temperatures are achieved, if a sufficiently long containment of the plasma is not obtained, a true thermonuclear reaction will not occur.

The so-called "pinch effect," the constriction of a high current discharge by its own magnetic field, has been under study since 1952 as a possible method of confining plasmas at thermonuclear temperatures. In the course of experiments it was found that the pinch was inherently unstable and broke up within a few millionths of a second after it was formed. By including a longitudinal magnetic field inside the pinched discharge it has been possible to increase the duration of the pinch to more than 20 millionths of a second.

Results with some of our newest machines indicate the attainment of temperatures in excess of 6 million degrees (Fahrenheit). At these temperatures and densities presently being obtained in the plasma, thermonuclear reactions should occur and neutrons have been detected. It is impossible at this time, however, to claim unequivocally that a thermonuclear reaction has been achieved since it has not been possible to rule out other mechanisms for the production of these neutrons.

Several of the witnesses warned, in this connection, that we should not become so preoccupied with the pursuit of thermonuclear neutrons that we neglect basic physics problems whose solution is essential to the achievement of our objectives. As one scientist aptly expressed it:

> We feel that in order to climb Mount Everest we must start, not by looking for snow, but by getting ourselves into the Himalayas. When we start seeing Sherpas and 20,000-foot peaks, there will be snow as a matter of course and we will then be ready to attempt a serious ascent.

The attainment of still higher temperatures is at present being limited by materials on the wall of the containment chamber which are contaminating the discharge and cooling the hot plasma. Larger diameter discharge tubes, using special wall materials, may ease this difficulty. Several devices are currently under construction or being designed which employ these larger tubes.

It was repeatedly emphasized that as we get closer to attaining our goal of a true thermonuclear reactor, there is no guaranty that nature will not develop additional ingenious ways of thwarting the efforts of our scientists. An operating thermonuclear reactor is still a long time off and even after this goal is reached, economic power will be many years away. If fusion power does become a reality, it will be a

cleaner form of nuclear power and there will be no fission products to contend with.

Much more research work will be required before we achieve a true self-sustaining fusion reaction. Further, it seems clear that experiments carried out on too small a scale physically are not likely to be successful; therefore, the trend will be toward larger devices.

Despite the difficulties which have been mentioned, the recent growth of understanding in this field has been unusually rapid. Several promising approaches are being pursued and there is little doubt among our scientists that the goal of power from nuclear fusion will eventually be achieved.

III. MAJOR THEMES OF HEARINGS

A number of major themes emerged during the course of the testimony of the 50 expert witnesses. Among the most notable of these were:

A. NEED FOR INCREASED LEVEL OF SUPPORT

There was virtual unanimity on the part of the experts who testified before the subcommittee that the United States as a Nation must increase the level of support of basic research—in the order of 50 percent or more—if we are to retain our scientific leadership throughout the world. The testimony strongly underlined the essentiality of providing increased financial support, both in terms of new research facilities and operating funds, so as to give the working scientists in our laboratories and universities maximum opportunities to develop their theories and talents to the fullest possible extent.

The working scientists were joined in their plea for increased financial support of our efforts by Dr. Warren Johnson, distinguished Chairman of the Atomic Energy Commission's General Advisory Committee, who has recommended, together with other members of his committee, that the operating budget of the Atomic Energy Commission's physical research program should be progressively increased from 50 percent to 150 percent over the next 4 years.

In a letter to Chairman Strauss of the Atomic Energy Commission, dated February 20, 1958, Dr. Johnson stated:

> * * * It is becoming more and more evident that the present level of support * * * is *greatly inadequate*. [Emphasis added.] Furthermore, unless considerably more support is forthcoming within the next 2 or 3 years, we shall find ourselves in a difficult position.

Dr. Johnson then went on to explain that particularly large expenses are being incurred in operating large-scale devices such as particle accelerators, adding:

> * * * What I would like to emphasize is that our greatest asset is well-trained scientific and engineering personnel and that we should give them full support in order to enable them to carry out their work to the capacity of their talents. I would estimate that the annual operating budget of the Division of Research at the present time should be at least $100 million to accomplish these objectives and that within the next 4 years this annual budget should rise to $150–175 million to make the fullest use of our manpower and facilities commensurate with the needs and objectives of the Atomic Energy Commission's program.

On April 3, 1958, the Atomic Energy Commission notified the Joint Committee—

> that the General Advisory Committee had adopted recommendations of its research subcommittee on the physical research program level of support, substantially identical to the personal views expressed by Dr. Johnson in his earlier (February 20) letter.

These observations have been amply supported by other materials available to the subcommittee and especially by field trips which have been taken by members of the committee and its staff during which

an opportunity was presented to talk at length with the working scientists in our laboratories. Such statements as: "We are finished as a first rate scientific power if we don't get increased funds," have not been uncommon during these field visits and the committee has been impressed with the earnestness with which our working scientists have urged a stepping up of our efforts.

B. ADVERSE EFFECTS OF BUDGETARY HOLDBACKS

Another major theme which emerged during the course of the hearings and inspection trips to field installations is the adverse effects which holdbacks of authorized funds have had on our physical research program in the various field installations where the actual research work is being carried out. These holdbacks have caused serious repercussions not only on the progress of our research projects themselves but have had the equally unfortunate effect of discouraging key scientists from remaining on the job.

Particularly in the major projects, such as the ones centered around costly experimental devices like large-scale particle accelerators, it is critical to the success of the project that a nucleus of competent scientists is recruited and kept together as an effective team to realize the full potential of these expensive devices. This takes time, and the disbanding of these key groups represents a major blow to the Nation in terms of its scientific resources.

What is needed, it was pointed out, is the upgrading of basic research on our scale of national priorities and the placing of a higher value dollarwise on basic research in relation to outlays for other national requirements.

C. NEED FOR EFFECTIVE USE OF LARGE CAPITAL DEVICES

Considerable emphasis was placed during the course of the hearings on the importance of providing our research scientists with the necessary tools for their work, including large capital devices such as high energy particle accelerators, research reactors, and mass spectrometers. These devices are utilized by our scientists to explore the basic nature of matter and to provide clues as to the nature of our entire universe. In the space age in which we are presently embarking, it is not necessary to dwell upon the importance of these explorations into the scientific frontier.

At the same time, it was emphasized that more adequate supporting facilities must be provided in many of our laboratories if we are to utilize fully the potentialities of these large experimental devices. It was pointed out that it is false economy to provide extensive capital outlays for such equipment and then fail to provide the necessary experimental working facilities for the scientists who are using these devices. Aside from a waste of public funds through underutilization of existing equipment, it was pointed out that failure to provide adequate supporting facilities results in a loss to the entire Nation in terms of delays in developing vital scientific information for our entire research program. These large devices are, in a very real sense, a major national resource and should be utilized to the greatest extent possible.

D. NEED FOR WELL-BALANCED PROGRAM

A fourth important point which was brought out at the hearings is the need for a well-balanced program of physical research. It is recognized that certain of our research projects are, by their very nature, more "glamorous" than other projects. Thus, our large particle accelerators are capable of capturing the public imagination because of their ability to "smash atoms" at speeds approaching the speed of light. Equally "glamorous" are efforts which are presently being made to develop controlled thermonuclear reactions for the production of power. The concept of "taming the H-bomb" and of deriving virtually limitless power from the waters of the sea has a dramatic effect on the public consciousness.

No one questions the great importance to our whole research program and to future scientific development in this country of the remarkable and ingenious research work which our scientists are performing both in the fields of high-energy physics and controlled thermonuclear reactions. This work is, in fact, vital to our research program and should receive our fullest support and encouragement.

But in focusing our attention on these more "glamorous" fields of scientific inquiry, it was pointed out, we should not make the mistake of allowing ourselves to neglect the support and encouragement of research work being performed in the other major areas of physical research; namely, chemistry and metallurgy. For the fields of physics, metallurgy, and chemistry are all closely interrelated in our research effort and without adequate support of all of them, we will inevitably weaken our entire effort to the detriment of all major fields of inquiry.

E. IMPORTANCE OF GRADUATE STUDENTS

The importance of producing adequate numbers of graduate students in the various major areas of physical research was repeatedly emphasized by many of the witnesses who appeared before the committee. While the results of basic research activity are of great importance to the Nation, it is equally important that in the course of this research work an opportunity is provided for the development of the exceptional student, particularly at the postgraduate and doctorate level, so that in future years we may have a reservoir of competent scientific talent. Such a reservoir of talent is indispensable to the maintenance of our scientific leadership and prompted several witnesses to refer to graduate students as "our most important product."

It was pointed out that constant attention and encouragement must be given to the development of these exceptional graduate students whose influence on basic discoveries and scientific advancement is historically far greater and more pronounced than the relatively small numbers of individuals involved.

The importance of providing incentives to young scientists was pointed up by, Dr. I. I. Rabi, of Columbia University, when he told the subcommittee:

> The difference of rewards in one way or another, either in public recognition or in monetary rewards, have been greater in other fields than in the scientific field. We must look to devise ways and means so that the rewards in the scientific field match those in other fields which are now attracting young people in large numbers.

As a means of providing such incentives, suggestions were made for greater aid to universities in their research programs, with particular emphasis on substantial participation by the universities in various projects under the physical research program. Reference was also made to the subcommittee's hearings on scientific manpower held in the spring of 1956, during which Dr. Rabi proposed a mathematics scholarship program to stimulate improvements in mathematics instruction at the high-school level. These recommendations have subsequently been introduced as legislation in the House of Representatives by Mr. Price and Mr. Van Zandt.

F. FREE-WORLD INTERDEPENDENCE

The interdependence of the free-world scientific community was brought out in the testimony of a number of witnesses. They pointed up the fact that no one nation has exclusive jurisdiction over basic areas of science and that much is to be gained through greater free-world cooperation in the exchange of scientific data and of scientists themselves. It was emphasized that great scientific discoveries usually are not made in a vacuum but rather are the culmination of many years of research by many scientists throughout the world. Even where such cooperation is lacking, as between scientists of the free world and Soviet bloc nations, it has been demonstrated that in fields such as controlled thermonuclear reactions, scientists of individual nations can arrive at substantially the same conclusions and results working independently of each other.

It was emphasized, in this connection, that we are presently engaged in a dramatic competition with Soviet scientists in the field of the so-called transuranium elements, some of which are as yet undiscovered. The identification and proof of existence of these elements is a matter of great significance to the scientific community, not only from the standpoint of the ultimate practical consequences of such discoveries but also from the point of view of world prestige. According to established custom, if Soviet scientists make these discoveries first, each successive element discovered in the transuranium range will automatically bear Russian names and will be so recorded in scientific textbooks and journals throughout the world.

For this reason, a number of witnesses emphasized the importance of providing our scientists with the necessary research tools, including costly accelerators and high flux reactors, to give them every opportunity to meet the Soviet challenge effectively.

G. PHYSICAL RESEARCH AS A BASE FOR APPLIED SCIENCE

Throughout the course of the hearings considerable emphasis was placed on the role of the physical research as an indispensable base for so-called practical applications of science. While it is difficult, if not impossible in most instances, to state what type of scientific "hardware" will eventuate from a given discovery in the field of physical research, it has been repeatedly demonstrated in the past half century that practical applications such as the dramatic American and Soviet satellites, and many more commonplace examples, owe their existence directly to prior discoveries which, at the time they were made, had no foreseeable "practical" applications. In explaining the distinction

between basic and applied research, Dr. Glenn Seaborg of the University of California Radiation Laboratory told the subcommittee:

> In basic research the motivating influence is not the attainment of utilitarian goals. Its keynote is curiosity, which is to be rated with the highest qualities of mankind. However, in actual practice basic research often turns out to be not really different from applied research in its real purpose. It is merely applied research with a time delay. It is virtually impossible to think of some scientific principle regarded as fundamental to the understanding of natural phenomena which has not been of great significance for the workaday world of mankind. But often it has taken years or even decades for this situation to appear.

The discovery of natural radioactivity at the turn of the century was cited by Dr. Seaborg as an outstanding example of this fact.

It was noted that the United States was provincial in basic research some 30 years ago in comparison to Europe, but that we are now occupying a position which is appropriate to our size, our wealth, and our institutions in the research field. It was pointed out, however, that as a nation we cannot maintain our scientific leadership if we do not give constant encouragement and nourishment to our basic research program. The penalty for indifference could well be the relegation of the United States to the status of a second-class scientific nation. Thus, while we have made great strides in the past 30 years and have overcome our inferiority to Europe in the research field, we cannot afford the luxury of resting on our laurels and failing to push forward vigorously in our research efforts.

IV. CONCLUSIONS AND RECOMMENDATIONS

1. From testimony received at the hearings and from personal visits to our laboratories in the field, the subcommittee has been impressed with both the breadth and quality of the work being performed by our scientists in the physical research program.

The United States can rightly be proud of the men and women in our national laboratories and universities who are dedicated to the task of insuring that the United States maintains its scientific leadership in an uneasy world.

2. The subcommittee is equally convinced that the Nation must provide our scientists with an adequate level of support of their research activities to insure maximum utilization of their talents and maximum progress in our research program. As regards the AEC physical research program, it is our opinion that the present level of support is inadequate to carry out this objective and that an increase of from 50 to 150 percent in the level of operating funds for this program should be provided over the next 4 years, effective immediately. This is in line with recommendations of Dr. Warren Johnson, Chairman of the AEC's General Advisory Committee (see p. 19) and with the testimony presented to the subcommittee.

Together with this increase in operating funds for the physical research program, the subcommittee recommends that funds for facility construction be substantially augmented so as to insure that the most effective use is made of our scientific talents and costly equipment in our laboratories. To do otherwise would be false economy and would jeopardize the progress of our entire basic research effort.

3. As a corollary to the need for increased level of support of the physical research program in the future, the subcommittee believes it is equally important that prompter action be taken by the executive branch in releasing funds which have already been authorized and appropriated by the Congress for specific projects in the field.

The subcommittee fully recognizes the need for a degree of budgetary control of expenditures and for the constant review of individual programs to insure that our funds are being spent wisely and effectively. This includes the weeding out and elimination of some projects which prove to be unworthy of further support from the point of view of technical development. At the same time, there is an equal need for keen judgment to insure that projects which are deemed worthy are pressed forward vigorously.

The subcommittee believes it is essential that our working scientists in the field receive prompt and clear information on the status of funds appropriated for their projects and are relieved, insofar as possible, of the administrative harassments connected with requirements for constant rejustification of individual projects. True economy is not effected when the working scientists must frequently interrupt their research work to perform such time-consuming administrative chores.

4. It is the firm conviction of the subcommittee that maximum

progress in the field of physical research requires a well balanced program in which adequate support is given to all of the three major areas of research activity; namely, chemistry, metallurgy, and physics. In a very real sense these major areas of scientific inquiry are interdependent and success in one very often is directly dependent upon success in the others. Without across-the-board support in all major areas of activity, the program as a whole will inevitably suffer.

5. In view of the continuing need for active encouragement and close supervision of the Commission's physical research program, it is recommended that the Commission take affirmative steps to reaffirm the importance of the General Advisory Committee as an active participant in the formulation of broad research policies and objectives, including the support level for the physical research program. Such high level attention is essential, in the subcommittee's view, if we are to realize the type of physical research program which is necessary to meet our national and international objectives.

6. It is recommended that the administrative machinery of the Sherwood program be strengthened, both within the Commission and in the field. Specifically, it would appear advisable to increase the permanent staff in Washington to permit closer attention to detailed developments as the program emerges from the strictly laboratory stage to the stage of engineering development with large-scale devices.

As to the program in the field, it is recommended that the present system whereby the program receives policy guidance from a steering committee made up of representatives of laboratories participating in the Sherwood program be replaced by a competent group of "outside" scientific advisers who would from time to time make policy recommendations as to the scope and direction of the program. It is believed that a group of this kind would be in a better position to make an objective analysis of the program and its objectives than members of the present steering committee who, by the very nature of the committee's representation, have special interests in individual projects.

7. The subcommittee notes with satisfaction that progress in declassification of information in the area of physical research has in general been good, but there are still a few areas, particularly the Sherwood program, where it appears advisable to ease current restrictions both as regards classification and access to available information. In view of the fact that the Soviet Union has reached a comparable stage of development in its development program on controlled thermonuclear reactions, the subcommittee believes that continued classification of broad areas of information in the Sherwood program cannot but work to the long range detriment of our own program by denying our own scientists the free interchange of ideas and information which is so necessary to scientific advancement.

It is noted, in this connection, that considerable "backup" research work needs to be done for the present Sherwood program which our national laboratories do not have time to do. This work could and should be done in our universities and by American industry. The easing of classification restrictions would facilitate contracting out such backup work. The subcommittee believes this would contribute materially to the ultimate success of our efforts and, at the same time, provide excellent opportunity for training of graduate students in this field. At the very least, we believe that exposing the difficult

technical problems involved in controlled thermonuclear reactions to a broader segment of the scientific community could not help but have beneficial effects on the program.

8. The subcommittee believes every opportunity should be taken to promote and encourage exchange of scientific information between the United States and the other countries of the free world. The subcommittee notes with particular satisfaction the results which have been obtained through participation of foreign students in the international school at Argonne National Laboratory. These students not only gain valuable experience to take back to their own countries but themselves contribute materially to our own research projects in this country. The subcommittee believes such exchange of scientists is one of the best means by which the free nations may accomplish their common objectives and at the same time provide, at modest cost, a reservoir of international good will toward the United States throughout the world.

It is suggested that such exchanges be broadened and increased in future years utilizing existing international organizations as the focal points for coordinating these activities. They will become particularly important as added premiums are placed upon the effective coordination of free world scientific talents by the new era of space exploration on which we are embarking.

9. Finally, the subcommittee wishes to reemphasize the importance of providing adequate, long-term support of basic research in this country. We as a nation and as a people must place a higher valuation dollarwise on basic research in relation to other national needs if we are to meet present and future needs of American science. Support of this research must be provided by many parts of our society including educational institutions, private industry, and the Government.

An essential foundation for such support is a better understanding on all sides of what basic research is and its importance to our future strength and security. It is hoped that this report, together with the published hearings, will help provide this understanding.

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